PERSPECTIVES ON THE USES OF BIOCIDES: CONSERVATION STRATEGIES FOR THE NEXT CENTURY

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Key words: India, biocides, DDT, wildlife

DDT has played a critically important role in anti-malarial programmes but future usefulness will be limited by increasing resistance of the mosquito vectors to DDT and other insecticides. In areas of past intensive use, DDT, in the form of its derivative DDE, has depressed the productivity of sensitive species of birds, leading in some cases to their local extinction. In India, environmental levels have appeared to remain below the threshold of chronic harm to wildlife, in part because of lower levels of use and in part because of high rates of loss to the atmosphere. DDT use could therefore continue in the anti-malarial programmes without environmental damage. The longer-term threat to biodiversity and species abundance from the continuing use of biocides, including insecticides, herbicides and rodenticides, in India, is expected to derive from harm to non-target organisms in the form of poisoning and reductions of the biomass that constitutes the food source.

Although there have been tragedies such as the loss of the cheetah (*Acinonyx jubatus venaticus*), and poaching is still a threat to the remaining tiger (*Panthera tigris*) populations, India has maintained a higher density and diversity of wildlife living in close proximity to people than any other nation on the earth, a consequence of the reverence for life inherent in the majority cultures. In spite of increasing human populations and their continuing encroachments into parks and reserves, the biodiversity and abundance of wildlife have remained relatively high during the current period of rapid economic growth. In this expanding economy, India has become not only a major consumer of biocidal chemicals in agriculture and in public health programmes but also a major manufacturer and exporter of these products. The *Farm Chemicals Handbook* 2001 reports that India, with China, is now the world's largest and only source of DDT and, with China, is now the world's largest user of DDT [Anonymous 2001; DDT: 1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane, related compounds and derivatives]. The American Bird Conservancy has reported that India now accounts for about 43% of the global yearly use and a substantial amount of the yearly production of 30,000 tonnes of the insecticide Monocrotophos (also known as Azodrin) (Anonymous 2002), one of the most poisonous chemicals ever sold to the public (Skripsky and Loosli 1994, Hudson *et al.* 1984); its use has frequently caused massive mortalities of birds (e.g. Mendelssohn and Paz 1977, Goldstein *et al.* 1999).

The decision by the Government of India on March 5, 2002, to accede to the Stockholm Convention on Persistent Organic Pollutants will eliminate the use of DDT in agriculture and limit its use in India to the control of malaria and other vector-borne diseases. The Treaty will also end the uses of 8 other chlorinated biocides which, like DDT and its derivatives, move through ecosystems, accumulate in food webs, and pose various degrees of hazard to both humans and wildlife. The era in which these chlorinated hydrocarbon "pesticides" were to have eliminated all vector-borne diseases and created a pest-free agriculture has ended; the once-promising technology had major inherent flaws. But the production and use of large amounts of other insecticides, herbicides and rodenticides, all included here under the label of "biocides," continues, with the specific aims of reducing populations of selected wildlife and plant species that are considered to be injurious to humans.

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A Centenary offers an opportunity not only to look back over the previous century but also to anticipate the next century with the experiences of the past as a guide. This essay will attempt to achieve some perspective on the "pesticide" issue with a focus on India, in part by addressing the significance of the continuing use of DDT in the malaria programmes. The word "pesticide", however, will be avoided; its use overlooks the reality that not only "pests" are killed by applications of these chemicals. Moreover, "wildlife" is defined to include insects and other invertebrates, so many of which have been the subjects of manuscripts published in this *Journal.*

A BROADER PERSPECTIVE

The human species is hardly unique in using chemicals to promote its survival and well-being. Three of the most familiar plant species in India, the tea (*Camellia sinensis*) and coffee (*Coffea* sp.) plants and the neem tree (*Azadirachta indica*), derive their usefulness to man from a complexity of chemicals that do not contribute to the metabolic processes that keep these organisms alive. Rather, they are the instruments of a sophisticated form of chemical warfare in which these and other plant species have engaged throughout their evolutionary history to avoid being eaten. Caffeine and a large number of other chemicals have served this purpose well. Strychnine, an alkaloid from the seeds of *Strychnos nux-vomica*, and rotenone from the roots of *Lonchocarpus* sp. and *Derris* sp. are other "natural" chemicals that have become potent biocides used by humans. An increasingly important group of biocides, the pyrethroids, are variations of the "natural" chemical pyrethrum which is synthesised by *Chrysanthemum cinerariifolium* and discourages its insect predators. Such chemicals are therefore used by both plants and humans for the same purpose.

In turn, biochemical processes have appeared throughout the evolutionary history of insects and other invertebrate plant consumers that metabolised or otherwise inactivated the chemical defences of the plants. The variety of biocidal chemicals used by humans does not yet match the arsenal used by other animals to eat or to avoid being eaten. Within this broader perspective, therefore, we might view the use of biocidal chemicals by humans as a "natural" act, but with critically important qualifications. The use of "warfare" chemicals by other species is highly selective and very rarely harms non-target species. Selective pressures, against the needless expenditure of energy, work to reduce the amounts of these chemical warfare agents to no more than what is necessary. Nature has therefore provided guidelines that humans might profitably follow.

Silent Spring

Not only did this book (Carson 1962) launch the environmental movement, its author has become its Patron Saint. Is this acclaim justified? The chemical industry vilified it for a number of years but appears now to have accorded it a measure of acceptance — it is hardly in the long-term interest of the industry to kill organisms that are beneficial or that maintain the biodiversity of food webs. Nor is it in its longer-term interest to produce products that threaten human health. Moreover, production of biocides that are substitutes for DDT and other chlorinated hydrocarbons has been profitable. Many, however, have criticised SILENT SPRING as "unscientific" or as scientifically flawed (e.g. Ames and Gold 1998). Advocates of DDT use continue to assail it; Ross (2000) has described the restrictions on DDT use as "the unfortunate legacy of the self-styled environmentalists, whose bible remains Carson's SILENT SPRING." If a balanced and scientifically accurate historical perspective on the merits of this book is to be achieved, a task this essay can only begin, these criticisms deserve to be fully and adequately addressed.

Rachel Carson was wrong in attributing the mode of action of the biocides then in use to a disruption of oxidative phosphorylation, the universal process that creates usable energy within the cell in the form of the ATP molecule. Yet she had assembled a vast amount of information and undertook what appears to have been the best possible synthesis at that time, a synthesis no one else was apparently even attempting. Later research was to demonstrate a broader and somewhat different diversity of biocide effects. An imperfect and inaccurate conclusion, which was nevertheless intellectually honest, about the way in which these poisons exert their effects, does not affect the validity of her principal themes that biocides are poisonous chemicals that were being applied in massive amounts to the environment where they were killing many non-target organisms, producing unintended and unanticipated results such as resistance, and posing potential dangers as yet unsuspected.

She was also wrong on the cancer issue, in assuming that the "natural cancer-causing agents" are "few in number" and that most of the modern cancers can be attributed to synthetic chemicals produced by humans. Rather, only a small percentage of the cancers not caused by smoking can be attributed to synthetic chemicals (Ames and Gold 1997, 1998). Apologists have pointed out that completion of the book was a race against her own impending death from breast cancer. Here also, however, she was providing an interpretation of the overall meaning of a considerable body of information about chemicals and cancer. The much larger amount of knowledge about environmental cancers, that has accumulated over the past 40 years, has not supported her interpretation that was based on a much smaller information base. Yet her attempts to assess the significance and to predict longer-term effects of the use and misuse of huge quantities of poisonous chemicals can only be considered as both intellectually honest and socially responsible, values that later environmentalists have not always maintained. Interpretations inevitably change as more information and more data become available.

Her explanation of the low productivity of populations of bald eagles (*Haliaeetus leucocephalus*) that was observed in 1947 in Florida (Broley 1958) and in a sanctuary established for bald eagles on the Susquehanna river [H.H. Beck, pers. comm. to R. Carson (Carson 1962)] was confirmed only some years later: "There is some occupancy of nests by adults, some production of eggs, but few or no young birds. In seeking an explanation, only one appears to fit all the facts. That is that the reproductive capacity of the birds has been so lowered by some environmental agent that there are now no annual additions of young to maintain the race." This explanation has since received full scientific support. The "environmental agent" turned out to be DDE, a derivative of *p,p'*-DDT, the active biocidal component of technical DDT. Its principal effect on sensitive bird species could never have been predicted — alterations of the eggshell structure such that the more contaminated eggs would either break or fail to hatch. Like other organochlorines, it moves readily throughout the global ecosystem; its non-polar character results in its accumulation in food webs, affecting those species at the top of the food webs that are sensitive to its effects. Carson's explanation, derived from the relatively small amount of information then available, could not have been more accurate — and scientifically sound.

Her documentation of the massive mortalities of non-target species, the futility of spreading large amounts of poisons over the landscape, and the inevitable appearance of resistance of the target species to biocides cannot be challenged. Her position as Patron Saint of the environmental movement is secure; imperfect interpretations in the public interest, in response to a genuine problem, have a value that is immune to the attacks of either commercial interests or the inflated egos of scientists defending an imperfect technology that they, to their credit, have helped to build.

How Bad is—or was—DDT ?

The deliberations leading up to the creation of the Stockholm Convention prompted another chapter in the continuing debates on the merits of DDT (e.g. Roberts *et al.* 2000, Smith 2000), with some environmental groups including World Wildlife Fund (Anonymous 1998, 1999a) and the Physicians for Social Responsibility (Anonymous 1999b) pushing for an ultimate global ban on the use of this chemical, with organisations such as the World Health Organization pointing out its continuing value to public health programmes (Kapp 2000), and with many individuals and organisations proclaiming either that the use of DDT has been one of the greatest achievements of human civilization or that its hazards justified an immediate global ban. At best, this essay will be only a modest first attempt at a definitive assessment of the pluses and minuses of a chemical that will — whatever the final verdict — have a prominent place in the history of technology.

Certainly, there is no disagreement that its use was spectacularly successful in the eradication of malaria in many areas of the world. By creating a temporary absence of mosquito vectors while the disease took its course in humans, the cycle of transmission was broken and the *Plasmodium* species responsible for the disease became locally extinct. But malaria has returned with a vengeance to Mumbai (Kamat 2000) and the rest of India (Sharma 1996). Would the eradication campaign in India have been successful, as it was in countries such as Taiwan (Yip 2000), had not the extensive use of DDT in agriculture hastened the inevitable appearance of resistance? Would a more concerted effort of spraying the walls of houses with DDT within a relatively short time period have resulted in success? These are questions for which no adequate answers are available, although it is likely that in both cases the answer would be positive. In any case their relevance to current policy is diminished; in India there is a high degree of resistance to DDT, and to several other insecticides, among the vectors of malaria (Sharma 1999); the current global emphasis in malaria control programmes is on treatment rather than the elimination of the vectors (Baird 2000).

Also, it cannot be disputed that DDT is still being successfully used to control and to eradicate malaria in some areas of the world (Dapeng *et al.* 1996).

The first objections to DDT came after the massive mortalities of birds, that followed its use, mainly at higher doses and particularly in a programme to "eradicate" the gypsy moth *Lymantria dispar* on Long Island in New York State, USA. The gypsy moth is an introduced species that each year has defoliated oak (*Quercus* sp.) woodlands of the northeastern USA. A lawsuit was brought in the 1950s against the US Department of Agriculture by Robert Cushman Murphy and Grace Murphy, to stop the "eradication" programme on the grounds that birds were worth more than the loss of foliage, which usually did not kill the trees, and that the programme was not working as the moths came back year after year. Although lost on technicalities, the lawsuit nevertheless exposed the weaknesses in the "eradication" concept and prompted the beginnings of change in public perceptions of "pesticide" use. So entrenched were these public perceptions that the Audubon Society, the major US conservation organisation at that time, did not support the lawsuit of the Murphys, nor would it provide a pre-publication endorsement of SILENT SPRING (R. Clement, pers. comm.).

The next lawsuit was brought in 1966 by a Long Island housewife, Carole Yannacone, who objected to a fish kill in a local marsh. Ultimately the court decided that it did not have jurisdiction, with no law upon which to base a decision, but the public awareness generated by the case resulted in the ending of DDT use in the local marshes.

In the autumn of 1968, American elm trees *Ulmus americana* were to be sprayed with DDT in the city of Milwaukee, Wisconsin, to combat the Dutch elm disease, caused by the fungus *Ophiostoma ulmi* which is carried from tree to tree by either of two species of beetles, the European elm bark beetle *Scolytus multistriatus* or the native elm bark beetle *Hylurgopinus rufipes.* The disease was then killing the elms over northeastern North America, where it had long been a cherished shade tree; in previous years the programme had killed many hundreds, probably thousands of birds. The Citizens Natural Resources Association, Inc. of Wisconsin, joined by the Izaak Walton League of America, requested a hearing that would determine whether DDT might be considered an environmental pollutant under Wisconsin law, which defines environmental pollution as "contaminating or rendering unclean or impure the air, land or waters of the state, or making the same injurious to public health, harmful for commercial or recreational use, or deleterious to fish, bird, animal or plant life." The hearing was undertaken in a courtroom format, with vigorous and frequently hostile questioning of witnesses. Critically important financial support was provided by the National Audubon Society, which was no longer neutral on the DDT issue.

I was privileged to participate in this hearing, initially to testify on the mobility of DDT, and later on the effects of DDT on pelicans and other fish-eating birds. Conflicts with industry representatives were frequent, and bitter. The species principally affected in Wisconsin were the peregrine falcon *Falco peregrinus* that had become locally extinct, the bald eagle that had almost disappeared, the osprey *Pandion haliaetus* that was producing thin-shelled eggs, and the double-crested cormorant *Phalacrocorax auritus* that was much reduced in numbers. In the state of Wisconsin, the value of these species and of the integrity of the ecosystem was considered higher than the economic benefits of a cheaper insecticide; the Hearing Examiner, Maurice Van Susteren, ruled that DDT met the criteria of an 'environmental pollutant' as defined by the law and its use ended in Wisconsin.

There were no public health issues to be addressed in Wisconsin. Ideology did not intrude on the relatively straightforward scientific arguments that were relevant to application of the law. On the industry side, however, ideological considerations occasionally obscured the defence of economic interests; the questioning of "pesticide" use was considered unpatriotic, seditious and perverse (e.g. McLean 1967).

Later, in 1970-72, the newly formed Environmental Protection Agency conducted hearings in Washington, D.C., to address the question whether the use of DDT should be ended on a national level. More than 100 witnesses participated, representing almost all facets of DDT use and documenting a wide range of environmental effects. Here also, confrontations between environmental scientists and the DDT industry were frequent and bitter. The Hearing Examiner, a retired lawyer with no scientific or environmental credentials, ruled that DDT did not constitute a danger to wildlife or people, but he was overruled by the Administrator, who found that continued DDT use posed an unacceptable potential risk to human health (Ruckelshaus 1972).

The wisdom of this decision continues to be challenged (e.g. Lieberman and Kwon 2002). The decision was supported largely by the possibility that DDT or one of its derivatives might be a human carcinogen, on the basis of rodent studies undertaken by the International Agency for Research on Cancer (IARC) using high amounts of DDT (Anonymous 1991, and earlier reports of the IARC). A vast amount of subsequent research has failed to find a link between DDT compounds and human cancers, including breast cancer (e.g. Adami *et al.* 1995, Ahlborg *et al.* 1995, Wolff *et al.* 2000, Laden *et al.* 2001). Yet this decision by Ruckelshaus in 1972 not to permit a continuing build up of DDT residues in the environment must be considered the only responsible one that could be made at that time in a country with no major problems of vector-borne diseases. It was just too early to make any definitive statement about the carcinogenicity or other adverse effects of DDT on humans; contamination of the global environment could not be quickly reversed if such an effect were discovered. The thinning by DDE of eggshells of a number of bird species, and depression of productivity in many of those species, provided an example of the deleterious effect of a synthetic chemical in the environment, that most likely would never have been predicted from the broadest range of toxicity tests in the laboratory. Similarly, a longer-term subtle but deleterious effect on humans might not be detected until years later. The same argument was used for ending the use of the polychlorinated biphenyls (PCBs), which also were produced in large quantities, and like DDT are mobile and persistent, and are accumulated in food webs (Risebrough and Brodine 1970). In the case of the PCBs, the validity of the argument has been abundantly vindicated; an entirely unexpected effect of the PCBs is a depression of learning capacity of human children exposed to PCBs in the womb (e.g. Darvill *et al.* 2000). Any increase above current levels of PCB contamination in the environment would have disastrous effects on human welfare; the release of large amounts of persistent, mobile, toxic chemicals into the global environment constitutes an experiment with unpredictable results. A policy that would prevent their accumulation is both sound and defensible.

Meanwhile, other persistent chemicals with demonstrated biological activities and which accumulate in food webs are now being detected throughout the global environment; the brominated diphenyl ethers, widely used as fire retardants, are an example (Kuehl and Haebler 1995, Noren and Meironyte 2000, She *et al.* 2002). Fluorinated surfactants, with unknown biological properties, have recently been detected in marine wildlife in concentrations that must be considered "high" (Giesy and Kannan 2002).

The lessons from DDT and the PCBs about the hazards of releasing large amounts of persistent mobile chemicals into the global environment have yet to be learned. Moreover, it is still not possible to conclude that DDE has had no harmful effects in humans. A report of an association between DDE levels and human premature births (Longnecker *et al.* 2001) might be compared with an earlier study of premature births of California sea lions *Zalophus californianus*. Concentrations of DDE in the blubber of female sea lions giving birth prematurely, in 1972 on the southern California island of San Miguel, were eight times higher than in females with full-term births. Yet, confounding factors, such as the possible presence of a disease factor, age, nutritional status, possible contributions by other contaminants and the absence of previous pregnancies, precluded any definitive conclusion that DDE was a contributing cause (Gilmartin *et al.* 1976). The hypothesis that DDE was at least in part responsible, however, remains valid, as does the hypothesis of a comparable DDE effect on humans. Although confounding factors may eventually be shown to be the responsible factors, an association between DDE levels and the duration of lactation of nursing human mothers (Gladen and Rogan 1995) appears to be another probable effect of DDE on humans.

Although solid evidence for an adverse effect of DDT use on human health remains elusive, the evidence for an adverse chronic environmental effect in the form of a depression in productivity of a number of bird species has strong and convincing scientific support. The Environmental Defense Fund, which undertook the legal challenge to the use of DDT in both Madison and Washington, other environmental groups, and individual environmental scientists had built their case against DDT on the basis of the scientific evidence for adverse environmental effects. DDE has been shown to produce eggshell abnormalities in these species, which result in either breakage of the eggs or their failure to hatch; the biochemical mechanism, however, is yet to be adequately described. Experimental studies have produced the same effect with concentrations of DDE that existed in the environment; other environmental contaminants such as the PCBs and methyl mercury produced no effects on the eggshells (Risebrough 1986). Following the national ban on DDT use, and the ending of the discharge of waste DDT into the sea from a manufacturing plant in Los Angeles, recovery of populations of bald eagles in eastern Canada (Grier 1982), ospreys of New England (Spitzer *et al.* 1978), brown pelicans *Pelecanus occidentalis* of California (Anderson *et al.* 1975) and peregrine falcons throughout North America (Cade *et al.* 1988) was rapid. Bald eagles are still unable to reproduce in the contaminated marine environment of southern California (Garcelon *et al.* 1989, Jenkins *et al.* 1994), but elsewhere in North America the environmental levels of DDE are generally now below the threshold for harm.

By the late 1960s, both DDT and PCB compounds were being detected in marine birds at concentrations that were likely to be above or near the thresholds of biological effects (Risebrough 1969, 1971, Risebrough *et al.* 1968). Recognition of the magnitude of this contamination (e.g. Goldberg *et al.* 1971) was a principal factor in changing perceptions about the scale of human activities within a global ecosystem of a finite size. DDT (or PCBs) used anywhere in the world would ultimately move into the global environment. However, in spite, of the earlier interest in global marine pollution, no recent data are apparently available that would indicate the magnitude or direction of current trends.

In summary: DDT played a critically important role in reducing the incidence of vector-borne diseases. Locally it is still effective for this purpose, but since resistance of the insect vectors to DDT continues to increase, its longer-term usefulness is low. Concerns about hazards to human health cannot be dismissed, but these hazards appear to have a lower risk of harm than a vector-borne disease. Its derivative DDE has the unique capacity to depress productivity of sensitive bird species, but only above environmental thresholds of harm. If low-volume use of DDT does not increase environmental levels of DDE to the threshold for the most sensitive species, environmental damage would not occur. Like other biocides, however, DDT may kill many non-target organisms and disrupt local food webs.

DDT CONTAMINATION OF THE INDIAN ENVIRONMENT

Press and internet communications have reported that the manufacturing capacity of Hindustan Insecticides Limited, a government-owned company that is the only producer of technical DDT in India, is in the order of 9-10,000 tonnes/year, that domestic consumption has been 3.5-5 tonnes and that an equivalent amount has been exported in recent years. It has not been possible to verify these figures and they are therefore considered to be estimates only. Data from the US Tariff Commission indicates that the production of DDT in the USA reached its peak in the mid 1960s at about 73,000 tonnes/year. If we assume that half of this was exported, then excluding Alaska, domestic use at that time was about 5 kg/sq. km/year. Indian domestic consumption at a rate of 3,600 tonnes/year would therefore be only 10% that of peak use in the USA, but since the land area of India is 39% that of the USA outside of Alaska, recent DDT use in India has been about 1/4 of peak US use on an area basis. Before considering other factors such as differences in rates of evaporation and loss, environmental effects in India would be expected to be lower than in the USA by a factor of about 4.

On the basis of information on population declines of peregrine falcons from North America and Europe (Hickey 1969) and available information about the worldwide effects of DDE on peregrine falcons (Peakall and Kiff 1979), it can be expected that the black shaheen *Falco peregrinus peregrinator*, the local peregrine race in India, might be the Indian species that would show the greatest depression of productivity and perhaps also a decline in population numbers. As a predator of other birds it occupies the top of the food web. There are apparently no data on productivity or on residue concentrations that would confirm or negate this prediction. Yet shaheens have continued to breed near Mumbai and continue to be seen in the city during the non-breeding season and elsewhere in India (R. Naoroji and L. Pereira, pers. comm.). Although inhabiting a country of relatively high DDT use, this race of the peregrine appears to have escaped the severe effects this species experienced elsewhere in its global range.

The North American bald eagle, feeding primarily on fish, occupies a somewhat lower position in the food web than does the peregrine falcon. Its productivity is, however, depressed at concentrations of DDE 4-6 times lower than the threshold that affects the productivity of peregrine falcons (Nisbet and Risebrough1994, Peakall and Kiff 1979). Although sensitivity to DDE, measured as effects on productivity, varies widely within the genus *Falco* (Fyfe *et al.* 1988), the Pallas's fish-eagle *Haliaeetus leucoryphus*, of the same genus as the bald eagle, is likely to show depressed productivity in response to accumulation of DDE. This species has not bred in Keoladeo National Park in eastern Rajasthan since the 1980s (V. Prakash, pers. comm.), but there are no data to suggest that DDE was a contributing cause.

The relatively few studies of the distribution of DDT compounds in selected bird species (Muralidharan *et al.* 1992, Ramesh *et al.* 1992, Tanabe *et al.* 1998, Senthilkumar *et al.* 2001) have shown that concentrations generally were about an order of magnitude lower than those associated with severe shell thinning and reproductive failures of related species in North America. Concentrations of DDT compounds in three Ganges river dolphins *Platanista gangetica* from the Ganges river at Patna (Kannan *et al.* 1994) were comparable to those in other species of dolphins in other areas of the world, except for the much higher levels that have been recorded in dolphins from California coastal waters (Table 1). Environmental levels of DDT compounds in India appear to have remained below thresholds of harm.

In part, this can be attributed to relatively high mean temperatures. The rate of volatilisation of DDT compounds into the atmosphere increases sharply with increasing temperature (Lloyd-Jones 1971, Risebrough 1990, Racke *et al.* 1997), enhancing their mobility through ecosystems. DDT leaving India, however, enters the oceans, thereby contributing to global contamination of the oceans, and constitutes a part of the DDT that has reached Antarctica.

CONSERVATION STRATEGIES AND POLICIES

When I was on the witness stand at the DDT hearings in Wisconsin in 1968, I was asked if a small amount of DDT could not be used, in Wisconsin, for any emergency purpose without contributing to environmental harm. The answer was "no." Peregrine falcons had disappeared as a breeding species, bald eagles had almost disappeared, the eggs of an increasing number of species were thin-shelled, and alarmingly high concentrations were being measured in marine wildlife. Environmental contamination levels were above the threshold of harm; any additional DDT would have increased the magnitude of damage. Today, except for the marine environment of southern California where bald eagles are still

Table 1: DDT in the blubber of Ganges river dolphins and dolphins from other areas of the world

Species	Locality	n	Date	Growth stage, Sex	Basis[7] Wet/Lipid	DDE[10]	Total DDT[10]	Reference
Ganges river dolphin[1]	Patna.	1	Oct 1991	Immature male	Lipid	- -	29	Kannan *et al.* 1994
	"	1	Jul 1991	Immature female	Lipid	- -	29	Kannan *et al.* 1994
	"	1	Mar 1992	Adult female	Lipid	- -	18	Kannan *et al.* 1994
Spinner dolphin[2]	Porto Novo, Bay of Bengal.	5	Mar 1990 - Jan 1991	Adults, 3 males, 2 females	Lipid	18	32	Tanabe *et al.* 1993
Bottlenose dolphin[3]	Porto Novo, Bay of Bengal.	4	Apr 1990 - Mar 1991	Adults, 2 males, 2 females	Lipid	9	11	Tanabe *et al.* 1993
Humpback dolphin[4]	Porto Novo, Bay of Bengal.	3	Apr 1990 - Mar 1991	3 adult males	Lipid	11	16	Tanabe *et al.* 1993
Striped dolphin[5]	Eastern Tropical Pacific.	14	Nov 1968 - Jun 1976	Adults, 4 males, 10 females	Wet	13	16	O'Shea *et al.* 1980
Common dolphin[6]	Southern California.	3	Nov 1968 - Jun 1976	Adult females	Wet	630	740	O'Shea *et al.* 1980
	Southern California.	10	Nov 1968 - Jun 1976	Adult males	Wet	850	970	O'Shea *et al.* 1980
	Southern California.	2	Nov 1968 - Jun 1976	Adult females	Wet	1,400	1,600	O'Shea *et al.* 1980
	Texas coast, Gulf of Mexico.	5	Jan 1990 - Mar 1991	Adult females	Lipid	3.7 [8]	- -	Kuehl and Haebler 1995
	Texas coast.	6	Feb 1990 - Nov 1990	Adult males	Lipid	37 [8]	- -	Kuehl and Haebler 1995
Beluga[9]	St. Lawrence river.	2	Nov 1983 - Sep 1984	Adult males	Lipid	80	93	Massé *et al.* 1986

[1] *Platanista gangetica*; [2] *Stenella longirostris*; [3] *Tursiops truncatus*; [4] *Sousa chinensis*; [5] *Stenella coeruleoalba*; [6] *Delphinus delphis*

[7] Since DDT compounds are associated with the lipid component of tissues, concentrations in the lipid are generally 125-330% higher than concentrations in the total blubber tissue, depending on the water content of the blubber, which generally ranges between 20 and 70 %

[8] Assumed to be the arithmetic mean

[9] *Delphinapterus leucas*

[10] Parts per million of the wet or lipid weight

unable to reproduce, the response would have to be a qualified "yes," the qualification deriving from an uncertainty about the longer-term trends in the contamination of the global marine environment. As long as environmental levels remain below a threshold of harm to the most sensitive species, any additional contribution of DDT to the ecosystem could not be considered as environmentally harmful. Particularly when in India the use of DDT in agriculture is to end, under the terms of the Stockholm treaty, opposition to the continuing use of DDT for house spraying in the anti-malarial programmes appears to derive from ideological considerations rather than from a pragmatic conservation policy.

The assumption that indoor use of DDT does not result in environmental contamination cannot, however, be supported. Studies in the Brazilian Amazon have shown that local contamination of soils and the food web of a nearby river resulted from the use of DDT to spray the interiors of houses in an anti-malarial programme (Torres *et al.* 2002). Volatilisation into the atmosphere and hence into vegetation, soil, water, etc., and back into the atmosphere, processes that are highly dependent on temperature (Risebrough 1990), are the pathways by which DDT compounds move from sites of application or deposition. A dramatic example from India is provided by the contamination of the soil and of the human population in the vicinity of a DDT manufacturing factory in Delhi (Saxena *et al.* 1987a, 1987b). Yet, on the basis of the argument presented above, DDT contamination resulting from continuing use in anti-malaria programmes in India will not be of environmental concern and need not be a component of a conservation strategy.

Among the other biocides to be banned by the Stockholm treaty, aldrin and dieldrin have done the greatest damage to wildlife (Nisbet 1988). The poisoning of sarus cranes *Grus antigone* in the vicinity of Keoladeo National Park (Muralidharan 1993) is an example from India that was documented, among the probably countless others that were not. These threats will diminish as the uses of the chlorinated hydrocarbon biocides end.

The major concerns in the past about the use, misuse, and overuse of biocides have derived from the effects these have had on the non-target organisms that constitute much of the Indian biodiversity, many of which have been described and discussed in the pages of the *Journal of the Bombay Natural History Society* over the past one hundred years. It is likely that these will remain the principal concerns throughout the foreseeable future. Reductions of the magnitude of these effects on wildlife and elimination of any adverse effects on humans might therefore be considered as the immediate goal; the longer-term goal must be the maintenance of maximum biodiversity. Whereas description and cataloguing of the Indian biodiversity have been a principal activity of the *Journal* over the past century, the maintenance of the scientific basis for the conservation and long-term survival of this biodiversity will surely be a major focus of the next century.

There are as yet very few hard data on the impacts, on populations, of reductions in available food supply following biocide applications. Applications of insecticides generally do not kill only those insects that are considered injurious to humans, but other insects and invertebrates as well, that are the food base for many birds and other vertebrates. Applications of herbicides kill plants that not only provide seed that supports seed-eating birds but also are the food source of many insects. Establishing monitoring programmes that would detect changes over the next century in the abundance of selected birds, other vertebrates, invertebrates, and plants may not initially appear to be an exciting scientific field worthy of participation and support. Yet if the problem is reframed to ask how changes in the abundance of species can be detected and measured, and how such changes can be adequately explained, it becomes a challenge to the best of scientific minds and of all available resources. It is such an approach that is needed, to assess not only the impacts of future use of biocides, but also of climatic change and all other factors that might affect species abundance and biodiversity. Moreover, without such scientifically sound information, it would be difficult to propose and to justify policies that would protect the biodiversity.

The excessive influence of the "pesticide" industry in California on the volume of chemicals used and the ways in which they were applied has been documented in a now-classic book by van den Bosch (1978). In India, economic interests of domestic manufacturers and the need for foreign exchange will inevitably become factors that influence biocide use patterns in both India and the countries to which the biocides are exported. An alert public that is well informed on technical issues is critically important in correcting balances towards the overall needs of society. Available information provided at the present time by the environmental groups, however, is woefully lacking in accuracy. If this essay were to convey any words of "wisdom" and advice, to the next generations that will work to conserve the biodiversity of India, a goal worthy of their effort, these words and advice would be to shed ideologies and to respect the integrity of technical and scientific information.

ACKNOWLEDGEMENTS

The research in India was supported by the Division of International Conservation of the U.S. Fish and Wildlife Service; I thank David Ferguson not only for his continuing support and encouragement but particularly for his commitment to the conservation of the wildlife of India. Research in India has been undertaken in collaboration with the Bombay Natural History Society, and the Sálim Ali Centre for Ornithology and Natural History. I thank J.C. Daniel for the invitation to present this paper and also for his assistance, many years ago, in finding birds and other wildlife in the Darjeeling area — an experience that established a lifelong appreciation for the wildlife and cultures of India.

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